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Tuning the antiferromagnetic easy axis direction in exchange bias bilayers

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Abstract

The exchange bias effect is measured for a Co/NiO bilayer before and after it has been cooled down from 580 K in 1.5 kOe magnetic field applied at 45° to the initial exchange-bias direction. The angular variation of the hysteresis loop shift for the treated sample showed three distinct minima and maxima, in contrast to that of the as-made sample, which is characteristic for a system with aligned ferromagnetic and antiferromagnetic easy axes. This behavior is qualitatively well explained in the framework of the domain-wall formation model applied for the off-aligned case.

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The continued interest in the exchange-bias effect, which results from the interfacial coupling between ferromagnetic (FM) and antiferromagnetic (AF) materials, is motivated by fundamental and technological interests. In almost all of the model works, the direction of the easy axis of the AF layer is aligned with the FM one; some numerical calculations using a simple Stoner–Wohlfarth model for the case of "off-aligned" coupling have been done by Xi and White [1]. Excluding the case of the perpendicular (or spin–flip) coupling, experimental works that report real exchange-bias systems for which the macroscopic AF and FM easy directions are not aligned, are scarce. Ström et al. observed, for temperatures close or above the AF blocking temperature, a rotation of the magnetization to a uniaxial easy direction different from the initial exchange-bias one, when heating up their Co/CoO bilayers [2].

In the present work, a FM/AF bilayer was deposited by magnetron sputtering onto Si(1 0 0) substrate at room temperature (RT) in 2.0 mTorr Ar atmosphere with base pressure before depositing better than 5×10^{-8} Torr. The film consists of 30 nm Co deposited on 50 nm NiO and capped with 5 nm Cu in order to prevent oxidation in air. Magnetic field of 0.5 kOe has been applied during the deposition. The structural characterization, made via conventional X-ray diffractometry performed on a Philips X'Pert MRD machine employing Cu Kα radiation, showed that the Co layer is strongly (2 2 0) textured, whereas the NiO contribution is a combination of evenly divided (1 1 1) and (2 0 0) NiO textures.

In-plane RT hysteresis loops were obtained by using an alternating gradient force magnetometer. No training effect, i.e., dependence of the hysteresis loop field shift, H_{eb}, on repeated magnetization reversal, has been observed. The sample was heated to 580 K, which is higher than the NiO Néel temperature of 520 K but rather lower than the Curie temperature of Co, and then cooled down to RT in the presence of a magnetic field of 1.5 kOe applied at 45 $(\pm 5)^\circ$ to the initial exchange-bias direction. Once again, effects of training have not been detected.

Fig. 1(a) shows the H_{eb} angular variations for both as-made and thermally treated samples, where the angle ϕ_H is defined as zero for magnetic field, H, applied along the initial exchange-bias direction. The $H_{eb}(\phi_H)$ curve for the as-made sample possesses one minimum and one maximum only, i.e., symmetry typical for the unidirectional anisotropy. The coercivity curve (not shown) has

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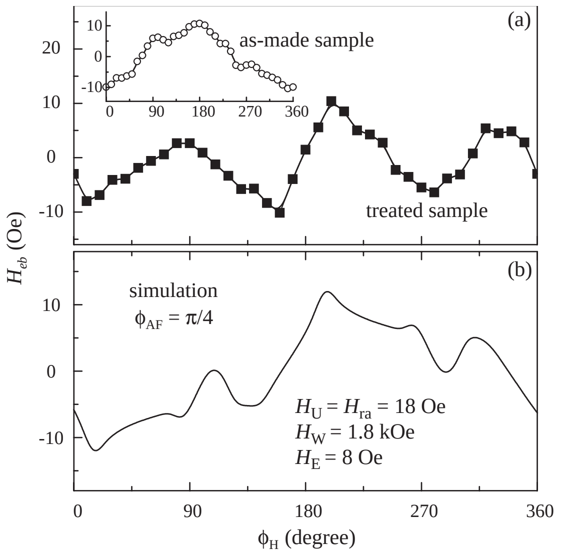

Fig. 1. Linear plots of the H_{eb} angular variations: (a) experimentally measured dependence for the thermally treated sample (the curve for the as-made bilayer is plotted in the inset for comparison); and (b) model curve for the off-aligned case; the parameters used are also given in the panel.

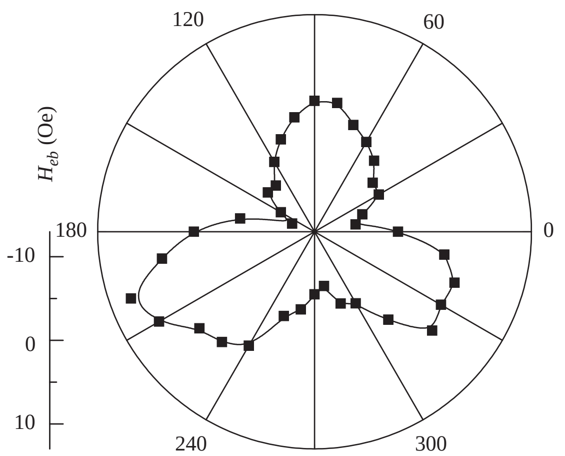

Fig. 2. Polar plot of H_{eb} versus ϕ_H for the thermally treated sample.

two well-defined maxima and minima. Both hysteresis loop shift and coercivity dependences are characteristic for a system with aligned FM and AF easy axes.

The $H_{eb}(\phi_H)$ for the treated sample, however, exhibits three distinct minima and maxima. This is better viewed in Fig. 2, which represents a polar plot of the $H_{eb}(\phi_H)$ given in Fig. 1(a). The coercivity shows the same type of symmetry, as compared to that obtained before the treatment, being the data slightly shifted upwards.

Panel (b) of Fig. 1 gives a $H_{eb}(\phi_H)$ curve calculated using the domain-wall formation model considering the off-aligned case, where ϕ_{AF} ($= \pi/4$) is the angle between the FM and AF easy axes. The definition of the parameters (the exchange coupling field, H_E, AF domain-wall anisotropy field, H_W, FM uniaxial anisotropy field, H_U, and rotatable anisotropy field, H_{ra}), as well as the numerical procedure used are described elsewhere [3–5]. Despite the visible quantitative difference (many factors not considered here, such domain-wall formation and motion at the FM side of the interface, distribution of H_E and H_W fields, etc., can be responsible for this discrepancy), there is a good qualitative agreement between the model and experimental curves, indicating that the FM and AF easy magnetization directions do not coincide for the treated sample.

This axis separation could be intuitively understood taking into consideration that during the cooling the FM moments line up with the field, the AF spins find new energetically favorable configurations due to the exchange coupling, and uniaxial anisotropy is induced in the antiferromagnet along the applied field direction. The starting temperature and the duration of the treatment, however, are not high enough to provoke such a reorientation of the FM axis. The strength of the FM anisotropy seems to be an important factor for such an effect to take place as well. We applied the same field cooling procedure on an identically prepared $Ni_{81}Fe_{19}$/NiO bilayer, and no significant changes have been observed for both coercivity and H_{eb} after the treatment. This can be attributed to the rather larger Co anisotropy as compared to that of the Permalloy: the measured coercivity of the Co/NiO sample was approximately six times larger than that of the $Ni_{81}Fe_{19}$/NiO one.

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